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Laboratory Tests of Motion Sickness Susceptibility

by
J. M. Lentz, Ph.D.
Naval Aerospace Medical Research Laboratory
Pensacola, Florida 32508
U.S.A.

SUMMARY

This paper reviews some of the laboratory tests of motion sickness susceptibility that have been evaluated over the years at the Naval Aerospace Medical Research Laboratory in Pensacola. The discussion focuses on 1) the procedures used to rate the extent of sickness; 2) how the intent of testing influences the outcome; 3) the problem of measuring adaptative potential; 4) aftereffects; and 5) the relationship of these tests to success in flight. Individual tests which are discussed include: Brief Vestibular Disorientation Test, Coriolis Sickness Susceptibility Test, Sudden-stop Vestibulovisual Test, Tilted-Axis Rotation Test, and the Visual/Vestibular Interaction Test.

INTRODUCTION

This paper is a review of five laboratory tests of motion sickness susceptibility that have been evaluated over the years at the Naval Aerospace Medical Research Laboratory in Pensacola. These tests, involving Coriolis stimuli, off-vertical rotation, visual/vestibular interactions, were developed with the objective of predicting individual susceptibility to airsickness and space sickness. However, there is much work left undone and this short review reflects some thoughts on both past accomplishments and future directions.

CORIOLIS (CROSS-COUPLED ANGULAR ACCELERATION) STIMULUS TESTS

Brief Vestibular Disorientation Test (1, 2, 3, 4, 5, 8, 9, 12, 13)

More subjects have taken this test than probably any other laboratory test of motion susceptibility. The Brief Vestibular Disorientation Test (BVDT) involves passively rotating an erectly seated S, with eyes closed, at a constant 90°/s. After 30 s at constant velocity the S makes 45° head movements (Fig. 1) every 30 s according to the following order: head right, upright, head left, upright, head right, upright, head left, upright, head forward, upright. The total time of rotation is 5 1/2 minutes. Following the BVDT each S completes a brief self-rate questionnaire concerning his reaction to the test, and is rated by observers for signs of motion sickness.

Figure 1
(a) (b)
Brief Vestibular Disorientation Device
Subject's head in the upright (a) and left-tilted (b) positions

Data (13) from a group of 552 student Naval Flight Officers (non-pilot category) is shown in Fig. 2. It is clear from this figure that rater (observer), self-rate, and follow-up (aftereffect) scores are strongly skewed toward high scores (high susceptibility). Due to the nature of this type of distribution this test may be useful in detect-

ing extremely susceptible individuals but is probably not useful in establishing even a rank order among most individuals of average susceptibility. This particular group of students is the subject of the next paper which traces their inflight incidence of airsickness through three phases of training. As you will see, their <u>inflight airsickness</u> does not correlate highly with their BVDT scores. Some of this low correlation is likely due to the skewed BVDT distributions and perhaps a different statistical approach (e.g., point biserial analysis) would improve these correlations. In one of the initial studies describing development of this test Ambler and Guedry (5) found that the BVDT correlated significantly with later <u>separation</u> from flight training for any reason (.165), tension or airsickness (.272), airsickness only (.413).

The low correlation with inflight airsickness is in part due to a) the brief one-shot test exposure which lacks the ability to estimate adaptative potential, and b) the somewhat mild stimulus which produces a highly skewed distribution of scores designed primarily to detect the extreme reactor.

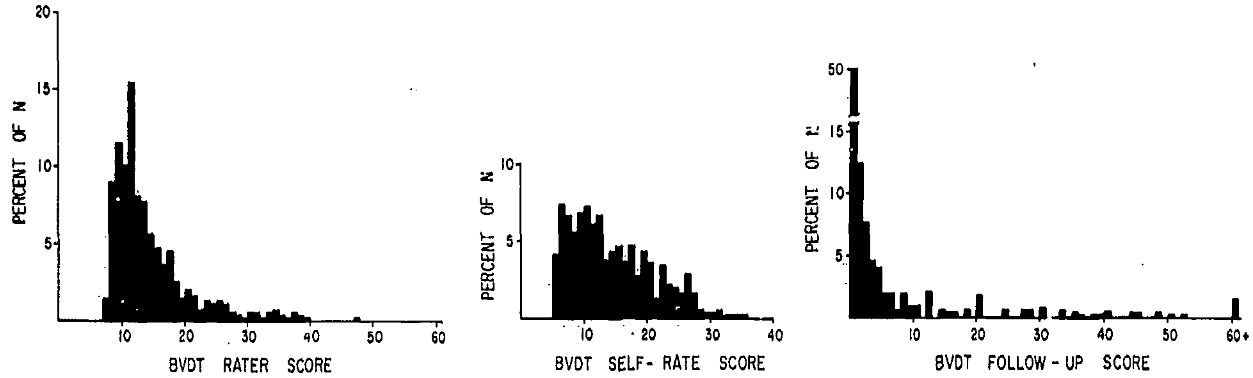


Figure 2

BVDT rater, self-rate, and follow-up score distributions (N=552)

<u>Coriolis Sickness Susceptibility Index (CSSI)</u> (14, 15, 16, 17)

Prior to discussing the Coriolis Susceptibility Index (CSSI), I want to mention an earlier test (the Dial Test) which had some influence in CSSI development and if it had received additional attention, could have evolved as a major test in this area.

The Dial Test (10) was an attempt to force specific head and body movements (Coriolis stimuli) and to relate a measure of performance to this stimulus/response complex. Figure 3 shows the response sequence required during rotation (7.5 rpm) on the Slow Rotation Room. In the initial report describing the Dial Test, Kennedy and Graybiel compared three groups of subjects: 100 incoming flight students, 40 experienced aviator pre-flight instructors, and 25 test pilots. The test produced sickness in 70, 30, and 5 percent of the respective groups (vomiting in 10, 0, and 0).

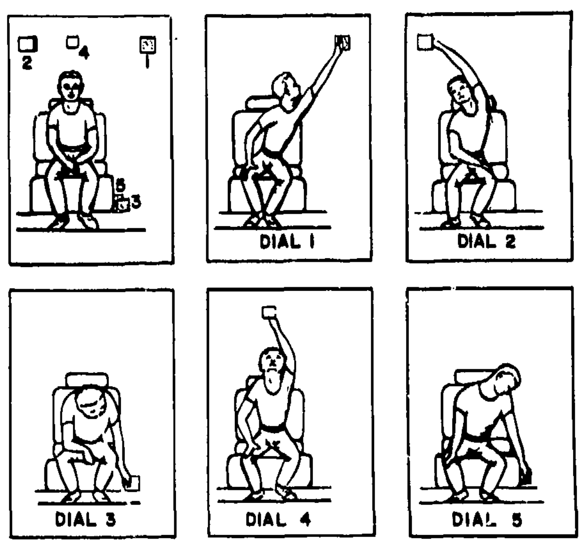


Figure 3

Dial Test -- Dial setting sequence

One difficulty with the Dial Test, and other procedures being used at the time, was the great range of symptom expression and the lack of a method to grade or rate the elicited motion sickness symptoms. Some investigators were using vomiting as an endpoint; however, this proved unacceptable to both subjects and observers particularly with repeated exposures. To remedy this situation Dr. Graybiel devised a method for grading the severity of motion sickness (7). This method for grading symptoms underwent several refinements and was combined with a set of head and body movements (Coriolis stimuli) to produce "a provocative test for grading susceptibility to motion sickness yielding a single numerical score." This test procedure has been generally called the Coriolis Susceptibility Index or CSSI (pronounced sissy).

The CSSI test required a seated subject to make 90° head movements in four quadrants according to the following order: front, upright, pause; right, upright, pause; back, upright, pause; left, upright, pause; front, upright, rest (Fig. 4). The chair velocity was determined by several preliminary tests and questionnaires and was limited to one of the following constant velocities (2.5, 5, 7.5, 10, 12.5, 15, 20, 25, 30 rpm). The CSSI scores were computed

by multiplying the number of head movements at the testing rpm by a factor E which was the average relative stimulus effect of a single head movement. In a separate study, Miller and Graybiel (17) found that the E factor could be expressed as a linear function of chair velocity (log x log) and that the duration of the test was usually less than 15 minutes. Fig. 5 shows a distribution of CSSI scores for 250 normal subjects (aviation related personnel). Inspection of the distribution reveals a strong skew toward high scores. Remember that with this test a low CSSI score indicates high motion susceptibility whereas a high CSSI score indicates considerable immunity to motion sickness. The distribution of scores on this test seems to suggest that it would be best suited for detecting individuals who are relatively resistant to motion sickness.

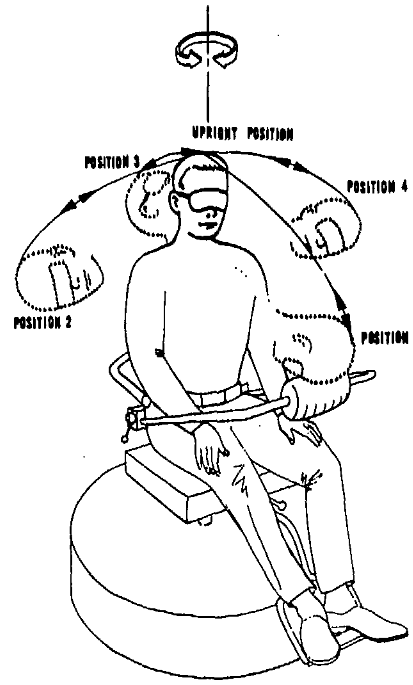


Figure 4

Diagram of standardized procedure for making each sequence of hed movements to and from tilt position 1 through 5 during chair rotation

To summarize these two approaches to Coriolis stimulus testing: the BVDT involves rating the degree of symptom expression to a nonvariable physical stimulus set (10 head movements over 5 1/2 minutes), the CSSI involves always taking the subject to a selected symptom level and then rating physical stimulus on the basis of its average vestibular stress value (E factor times the number of head movements). As currently designed each procedure results in a strongly skewed distribution of scores. The BVDT may better detect an extremely susceptible individual and the CSSI may better detect an extremely resistant individual. Neither test attempts to provide a measure of adaptative potential. Adaptative potential is a factor that will have to be measured if we are to improve these rating methods; however, the problem is how to do this both accurately and with a short period of testing. It is my opinion that the two or three repeated exposures will not provide an adequate estimate of adaptability. However, a second exposure to a cross-coupled stimulus will probably yield a better estimate of current susceptibility since it will not be contaminated by the unexpectedness of the experienced motion (occasionally a 'fear' reaction).

VISUAL-VESTIBULAR CONFLICT TESTS

Visual-Vestibular Interaction Test (12, 13, 19)

In the Visual-Vestibular Interaction Test (VVIT) the erectly seated S is passively and sinusoidally oscillated at 0.02 Hz with a peak angular velocity of $\pm$ 155^{o}/s while he attempts to retrieve data from a visual display. The axis

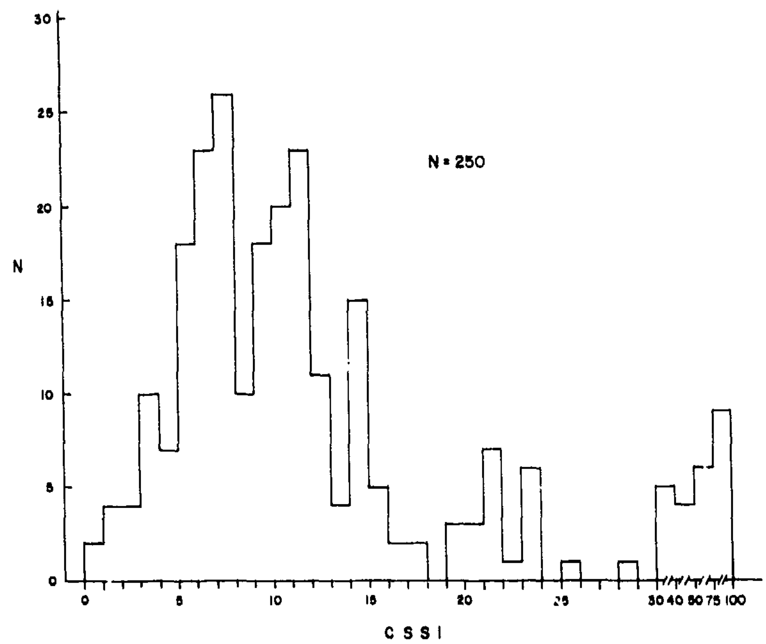


Figure 5

Distribution of Coriolis Sickness Susceptibility Index (CSSI) among 250 normal subjects.

of rotation is vertical and the S is encapsulated within a chamber (Fig. 6) which remains completely dark until presentation of the visual display (Fig. 7). Subjects are instructed to use the coordinate system to find the corresponding digit embedded within the matrix. Once the digit is located, the S reports it along with the next two digits below it. Coordinates are issued via a tape recording every 7 s, with a total of 42 commands. Following the test each student completes a brief questionnaire concerning his reaction to the test and two observers rate the magnitude of overt motion sickness signs. The rater, self-rate and follow-up scores on this test are almost identical to those used with the previously mentioned BVDT procedure. The resulting distributions are shown in Figure 8 and again they are skewed toward higher scores (stronger signs/higher susceptibility).

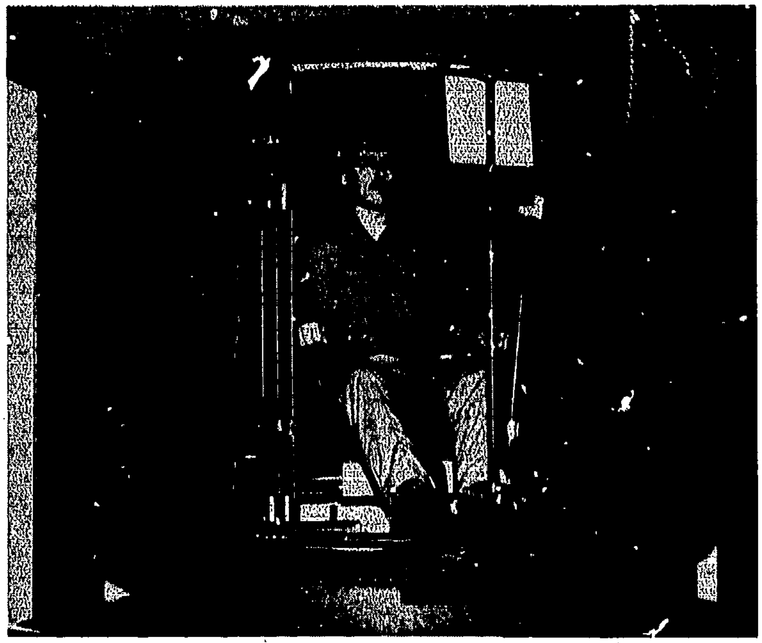


Figure 6

Visual-Vestibular Interaction Test Device
During testing the black shroud completely occluded the subject's external visual reference.

	A	B	C	D	E	F	G	H	I	J	K	L
1	7	1	1	8	2	4	3	1	6	6	9	4
2	6	4	4	2	4	3	1	8	9	7	4	1
3	2	2	3	4	7	8	6	5	1	4	8	5
4	9	9	5	4	6	2	7	3	8	3	7	9
5	8	1	4	3	6	5	7	7	1	4	2	6
6	7	4	7	1	8	1	9	6	3	2	8	5
7	1	7	6	7	6	4	9	5	4	8	3	7
8	7	1	3	3	4	8	9	4	2	5	6	8
9	6	2	1	6	7	3	8	9	7	2	6	6
10	1	7	5	9	9	1	5	6	6	3	5	8
11	9	3	6	7	3	2	2	8	4	5	2	5
12	2	7	6	2	9	9	3	4	1	5	1	7

Figure 7

VVIT Visual Display

It may be interesting to note that during development of this test it was found that the display complexity played an important role in establishing the nauseogenic quality of the test. For instance, using the same physical vestibular stimulus, a 3 digit display was typically not nauseogenic whereas a 7 digit display was somewhat nauseogenic and the 12 x 12 matrix was quite nauseogenic (12% abort the 5 minute test). One would suspect that this test would be useful in detecting those individuals who get motion sick while reading in a moving vehicle (e.g., navigation duties); however, it has a generally low correlation with reported inflight airsickness. I should note that with repeated exposures (ten sessions) I have personally adapted fairly rapidly to this stimulus situation whereas I have had only limited success adapting to a cross-coupled stimulus with much more exposure. I am particularly enthusiastic about this procedure since it offers a situation where the rate and/or severity of sickness can apparently be altered by changing a static display without necessitating changes in the motion condition - in other words, we may be able to change display dynamics; however, we probably won't be able to change aerodynamics.

The Sudden-Stop Vestibulovisual Test (6, 11)

The Sudden-Stop Vestibulovisual (SSV) test involves accelerating ($15^\circ/sec^2$) a subject to a constant velocity ($300^\circ/sec$), holding at that velocity for 30 sec and then rapidly decelerating (1.5 sec) to a stop followed by a 30 sec rest. This basic sequence is repeated 20 times with eyes blindfolded then an additional 20 times with eyes open and

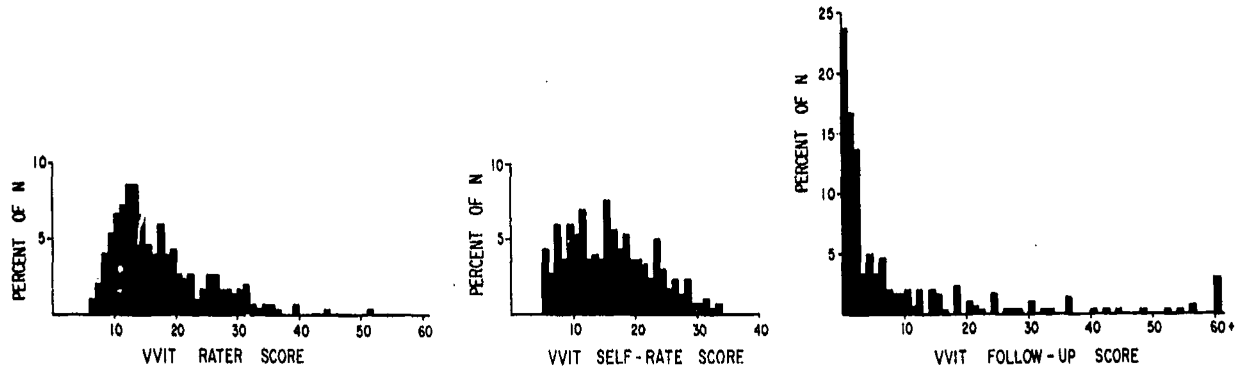


Figure 8

VVIT rater, self-rate, and follow-up score distributions

then if necessary another 20 times again with eyes open, but using the opposite direction of rotation. In the eyes open condition the subject views a dark cylindrical surround which has 6 vertical white stripes (Fig. 9). Each individual continues exposure until they reach the slight "nausea" endpoint as defined by the diagnostic grading procedure developed by Graybiel, et al. (7,14,16,17). When this point is reached each subject receives a score which is one-half the number of stops with eyes covered plus the number of stops with eyes open plus twice the number of stops after the direction of rotation has been reversed. Since this procedure has only recently evolved, a normative data base on a large population is not yet available. When more data are collected with this procedure, the arbitrarily assigned weights for the different stop procedures can be better evaluated. This test also seems to have a novel (possibly fear) component which is present on first exposure (7/14 aborted during eyes closed) but which is less evident on the second exposure (1/14 aborted during eyes closed).

Because we normally function with our eyes open, particularly in motion situations, I propose that continued work on visual-vestibular interaction tests will prove to be the best predictors of motion sickness in most human performance systems.

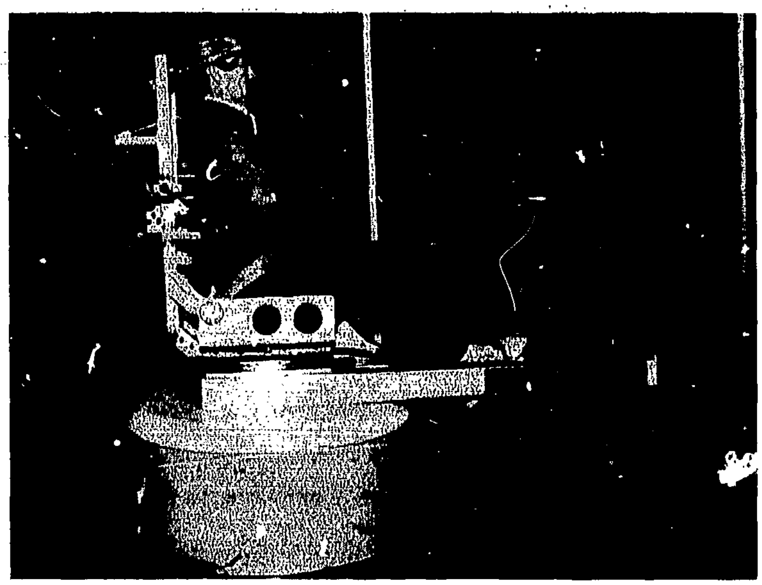


Figure 9

Test chamber and rotator used for the Sudden-stop Vestibulovisual Test

OFF-VERTICAL TESTS

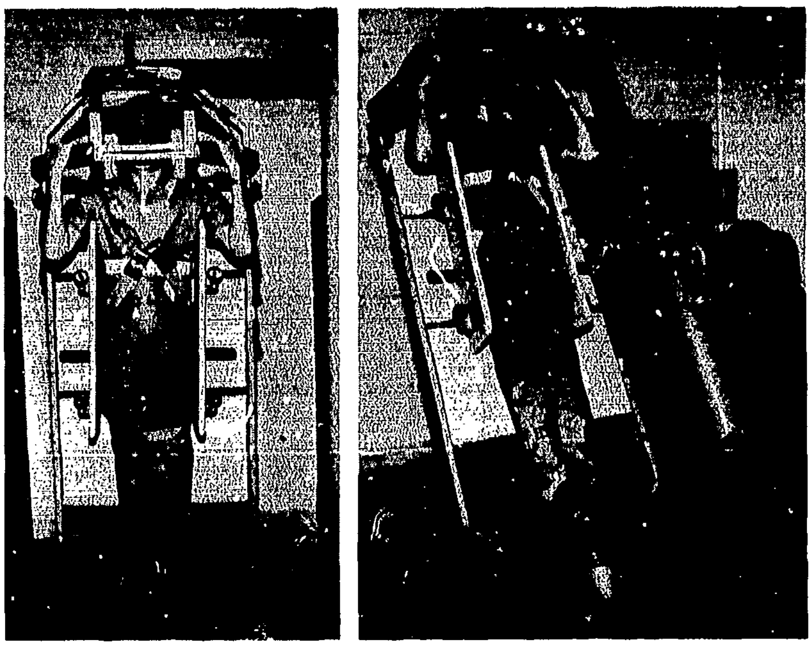
Tilted Axis Rotation Test (TART) (12)

In the TART, the erectly standing S is securely fastened in a litter device capable of rotation about an axis that can be tilted relative to gravity (Fig. 10). The S is blindfolded and tested in a darkened room. In the first trial, the S is accelerated at $25^{\circ}/s^2$ in a clockwise (CW) direction with the axis of rotation vertical, i.e., aligned with gravity. The acceleration is terminated upon reaching $60^{\circ}/s$ (10 rpm), and this constant velocity was maintained for 90 s and then the S is decelerated at $25^{\circ}/s^2$ to a stop. The second trial is identical to the first, with the exception that rotation is in a counterclockwise (CCW) direction. In the third and fourth trials the axis of rotation

is tilted 30° off-vertical (Fig. 10) and, with the axis remaining tilted, the rotation velocities and accelerations described in Trials 1 and 2 are repeated. The S is always stopped in the nose-up position. In the fifth and sixth trials the S remains tilted at 30° off-vertical and again is accelerated at $25°/s^2$. A constant velocity of 102°/s (17 rpm) is used for this pair of trials. The interval between trials is approximately 5 minutes. Following the test each subject completes a brief self-rate questionnaire concerning his reaction to the test and is rated by observers for signs of motion sickness. The rater and self-rate procedures are identical to those used in the previously mentioned BVDT and VVIT. Since it is not uncommon for subjects to terminate the TART prior to its completion, the rater and self-rate scores were weighted with respect to the number of trials completed. Rater and self-rate scores of individuals completing six trials were multiplied by 0.65, since approximately 65 percent of a random unselected group of subjects completed six trials. In a similar manner the scores of individuals completing five trials were multiplied by 0.73, four trials were multiplied by 0.90, and three trials were multiplied by 0.98. Subjects who were unable to complete an off-vertical trial (third trial) were assigned their raw scores. This method of weighting rater and self-rate scores on the TART is arbitrary and may need future revision. Data distributions for an airsick group (N=47) and an unselected or 'comparison' group (N=80) are shown in Fig. 11.

Another off-vertical procedure (18) has been used to generate motion sickness symptomology at Pensacola; however, it has not been administered to a large normative population. Miller and Graybiel (1970) rotated a seated subject at one of several selected velocities (2.5, 5, 10, 15, 20, 25, 30, 40, 45 rpm) and after 60 seconds tilted the rotating chair at 5°/sec to a tilt position selected from among 2.5, 5, 7.5, 10, 15, 20, or 25 degrees (Fig. 12). The rotation continued for one hour or until moderate malaise was elicited. With the limited number of individuals tested with this procedure, it appears that the test duration varies between 5 and 20 minutes depending on the extent of the off-vertical axis.

It may be interesting to note that the first procedure (TART) appears to be more nauseogenic than the second procedure. This difference is most likely due to the fact that the second procedure uses constant rotation for up to one hour to elicit symptoms whereas the TART uses a short series of acceleration/decelerations. In a blindfolded subject, the strongest otolith-canal conflict would be associated with decelerations and therefore the increased number of decelerations in the TART probably accounts for its increased nauseogenic value. In general, these off-vertical procedures do not seem to elicit a strong 'fear' reaction on initial exposure.



(a) Figure 10 (b)

Tilted-Axis Rotation Device: (a) vertical position; (b) 30 degrees off-vertical

GENERAL DISCUSSION

Desirable traits for a motion sickness susceptibility test

a. Any laboratory test of motion sickness susceptibility will be judged primarily on its ability to generalize to other exposure situations. The premise that motion sickness is a personal trait which should basically generalize across motion conditions is a most important concept and is the basis of much of our testing although there are questions about idiosyncratic susceptibility to particular motion stimuli. With a group of unselected subjects, correlations between the BVDT, VVIT and TART were fairly high ($r \approx 0.5$) and statistically significant (12). However, with airsick referrals the intertest correlations (rater and self-rate) were low and generally not significant. Because these tests are

.. ·ntionally fairly mild and designed to detect susceptible responders they lack resolutio.. among airsick referrals. It is possible that resolution among airsick referrals could be improved by adjusting the difficulty of each test in an effort to elicit measurable reactions which would better resemble a normal distribution. In this regard, taking every individual to a selected symptom level might improve intertest correlations.

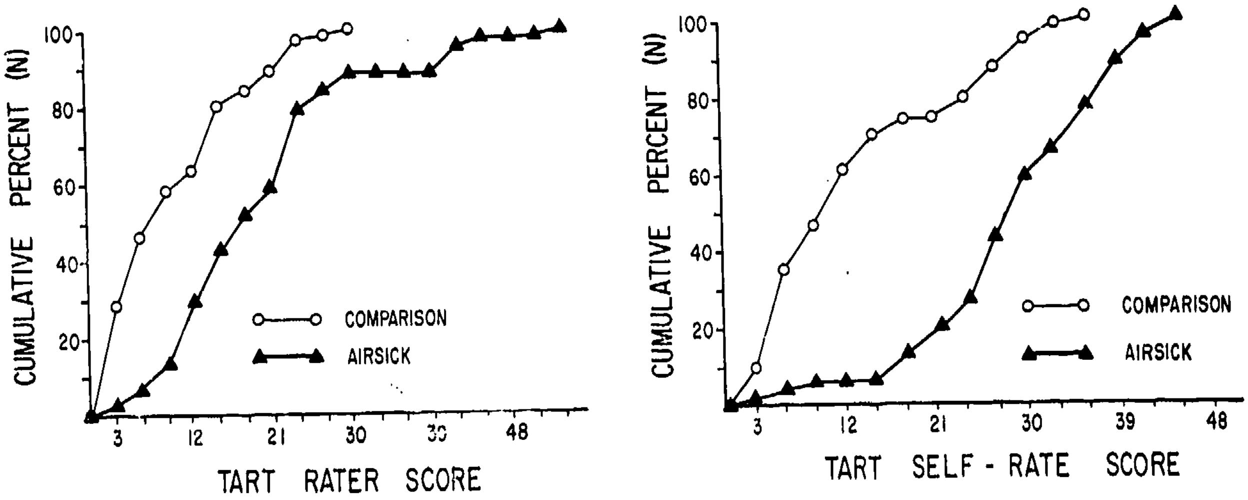


Figure 11

Cumulative percent distributions for TART rater and self-rate scores.

In general, all of these tests have had fairly low correlations with field conditions. How can prediction or generalizability be improved? For a mass testing situation (i.e., all pilot candidates), one would have to consider reducing the false positive predictions and therefore an even milder test may better identify the really extreme responder. Although the incidence of false negative predictions would be high in this case, if the identification of positive cases were always correct, then selection personnel would surely be quite interested. If testing is limited to small groups or individuals, then test development should probably focus on approximating the field condition (both stimuli and duration of exposure) as closely as possible which ideally will reduce the generalizability problem. Accuracy of testing might also be improved by developing objective physiological monitoring of symptoms instead of relying on observer ratings or self-rate reports. It is my opinion that although these systems would be nice, they are not yet needed. Although the methods of subjective observation are not technologically impressive, they are more than adequate for identifying the major sickness symptoms which tend to affect performance and motivation.

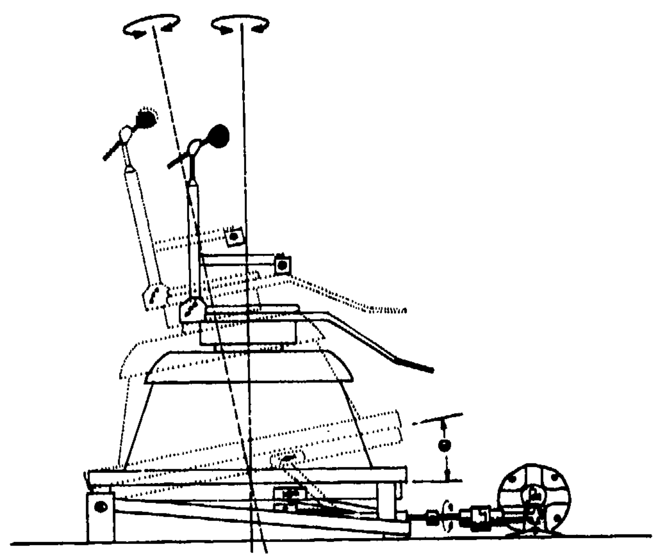


Figure 12

Diagram of apparatus used in off-vertical rotation test.

b. A laboratory test of motion sickness susceptibility needs a measure of adaptative potential. In most cases where these tests have been administered to the same subjects on a repeated basis the testing objective was not to measure adaptative potential but to measure test-retest reliability or to serve as the basis of evaluating drug effectiveness etc. and the intervals between exposures have been long in an effort to minimize adaptative shifts. The time involved in repeat exposures is for many users unacceptable and if for

no other reason, I would guess that this approach to measuring adaptative potential will not survive. A quick measure of adaptative capacity might ultimately be obtained by measuring a CNS perceptual aftereffect which superficially may not seem directly related to the vestibular system (i.e., visual spiral aftereffect); however, this will not be easil accomplished.

Many people overlook the possibility of estimating adaptative potential by measuring the magnitude and duration of aftereffects during recovery from a single exposure. One problem with this approach is its dependence on a truthful subject report. I believe more effort will be made to measure aftereffects particularly because of the numerous reports of sickness and aftereffects following flight simulator exposure. This area will also receive attention due to the increasing concern for the protection of our human subjects once they depart the testing environs.

c. A third trait that is desirable for a laboratory test of motion sickness is a short administration time. In situations where large numbers of flight candidates are being tested, 20-25 individuals must be tested in no more than 3-4 hours. This factor loses importance in situations limited to small groups or individual subjects.

d. Ideally the perfect motion sickness susceptibility test would not need specialized equipment or highly trained personnel - and thus the cost of administration would remain low. This is the least important factor and could be overlooked if the other factors can be maximized.

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DISCLAIMER

Opinions or conclusions contained in this report are those of the authors and do not necessarily reflect the views or endorsement of the Navy Department.

DISCUSSION

KUEHN: I'm interested in your remarks on the complexity of a target and proclivity to motion sickness. I've always thought that distraction of the type you indicated reduced incidence of motion sickness, yet you indicate that it might be worse. This has implications for space motion sickness. Perhaps some of our space protocols should be more simplified than they are.

LENTZ: Yes, it seems crucial. As you increase display complexity it appears that you also increase motion sickness incidence (example 3 digits - 7 digits - 12 x 12 matrix).

JONES: Our experience has been that some fliers getting airsick try to ignore their premonitory symptoms and thus find themselves..rather suddenly vomiting. This is the antithesis of what our lab was teaching, that they should attend to their symptoms and diminish them by relaxation procedures. Could this effect at least partially account for your finding that complexity of visual task was positively associated with motion sickness?

LENTZ: In many cases a susceptible individual concentrating on performing the matrix task without error and having no error still exhibited very strong nauseogenic responses. In sum, just concentrating on the task doesn't seem to alleviate the sickness much.

MONEY: I understand that the Israeli airforce uses a technique whereby early in the selection process the candidate prospects are put into a transport aircraft.

LENTZ: If we look at people who are not sick and I'm talking about the P3 aircraft now, I don't have the information for all of the different squadrons, then only 17% of those are getting sick when they get into the fleet readiness squadron in the P3 aircraft.